



Projections, Datum, Coordinate Systems, and Units of Measure Standard

The goal of the Standards and Recommendations Committee is to provide recommendations and guidelines to Indiana GIS user communities to facilitate the collection, maintenance and analysis of GIS data; and, to communicate existing federal, state and local data standards. The Data Standards and Recommendation Committee will not recommend software, hardware or operating systems. Furthermore, the Data Standards and Recommendation Committee will not impose any of these recommendations and guidelines as a requirement on any GIS user community.

Introduction

The purpose of this document is to provide background information about projections, datum, coordinate systems, and units of measure and to document where and how they are used in Indiana. It is not the intent to suggest that one standard be implemented by all, rather to allow each to select what works best for their own needs. The following are considered de-facto standards because of their widespread use. Their adoption would assure that your data are internally consistent, and consistent with others developing data for the same or similar geographic extents.

Recommendations

MULTI-STATE, STATEWIDE, AND MULTI-COUNTY

Federal and state government agencies and other organizations that use multi-state, statewide, or multi-county data sets generally project the data using a Universal Transverse Mercator (UTM) projection. UTM distances are usually expressed in meters. NAD 83 is typically used as the horizontal datum and NAVD 88 for vertical datum for statewide data sets.

COUNTY AND LOCAL

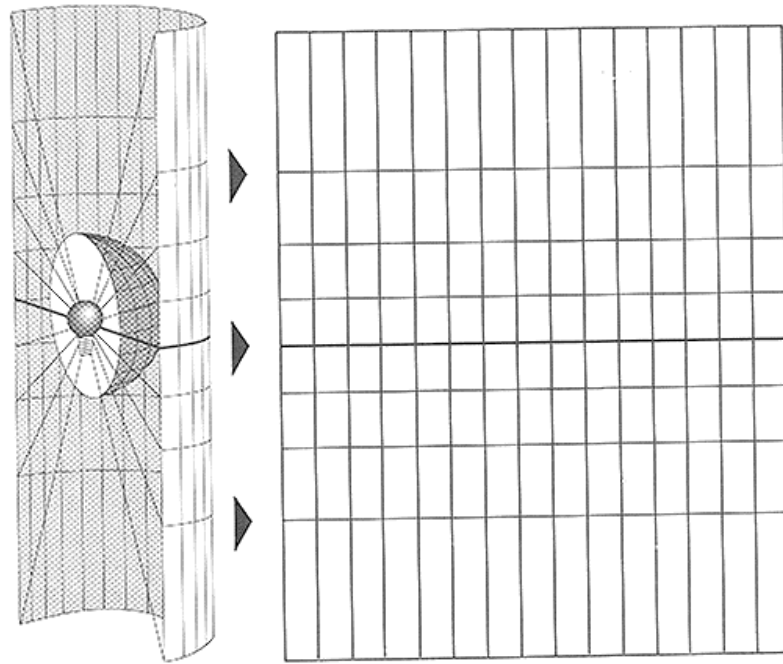
County and city governments in Indiana, and other agencies looking at county and local level data, sets typically use the State Plane Coordinate System. State Plane distances are usually expressed in U.S. Survey Feet when using NAD27 datum, and meters when using NAD83. Indiana is represented by two State Plane Coordinate System zones: Indiana

East and Indiana West. NAD 83 is typically used as the horizontal datum and NAVD 88 and for vertical datum for statewide data sets.

The following four sections (1.Projections, 2.Datum, 3.Coordinate System, 4.Units of Measure) provide background information to help you understand and interpret the above recommendations.

1. Projections

Cartographers are challenged to represent 3-dimensional information (the earth's surface) in two dimensions (a piece of paper). One solution to this problem is to use a globe rather than a plane. Globes provide the smallest distortion of features, however globes are expensive, difficult to mass produce, bulky, difficult to use to measure distances and features, and the user is unable to see objects on both sides of a globe at the same time.



However, the earth is not flat. Therefore, in order to depict a three-dimensional object on a flat plane (i.e. a piece of paper), you must project the object. Projections need to accurately portray the surface of the earth in terms of:

- Shape
- Area
- Distance
- Direction

Why are there so many projections?

When three dimensions are reduced to two, one or more of these characteristics will be sacrificed. Therefore, projections are created and used to accurately portray characteristics that are most important. For example...

- Conformal projections preserve local shapes
- Equal-area projections retain all areas at the same scale
- Equidistant projections maintain certain distances
- True-direction projections provide accurate directions

Conformal projections

- Preserve local shapes.
- To preserve individual angles describing the spatial relationships, a conformal projection must show graticule lines intersecting at 90-degree angles on the map.
- The drawback is that the area enclosed by a series of arcs may be greatly distorted in the process.

Equal-area projections

- Retain all areas at the same scale. All other properties are distorted.
- In some instances, especially maps of smaller regions, shapes are not obviously distorted, and distinguishing an equal area projection from a conformal projection may prove difficult unless documented or measured.

Equidistant projections

- Preserve distance between certain points. Scale is not correct except along specific lines which are based upon which projection is used.
- No projection is equidistant between all points on a map.

True-direction projections

- The shortest route between two points on a curved surface such as the earth is along the spherical equivalent of a straight line on a flat surface – called the great circle.
- True direction – or azimuthal – projections maintain some of the great circle arcs.

How can I choose a map projection?

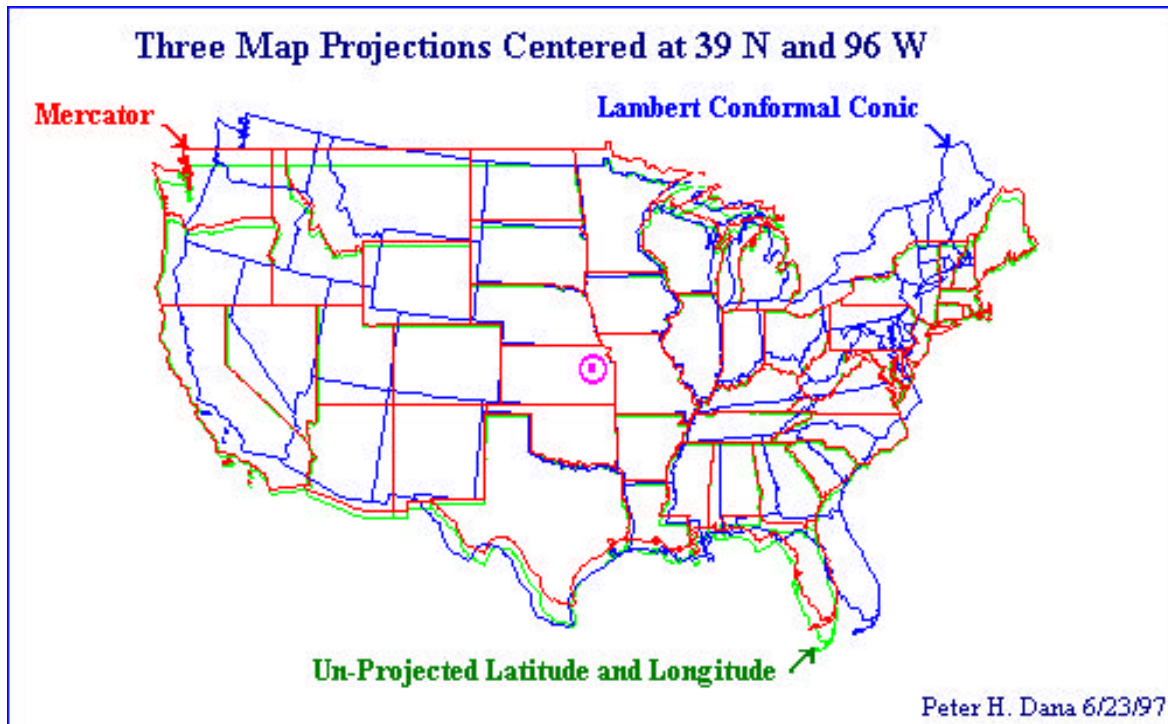
The purpose of the map, its scale, and the geographic extent of the mapped area dictate the selection of a map projection.

Purpose	Key feature	Example
Navigation	True direction	Mercator
Road Maps	Equidistant	Azimuthal
Thematic Maps	Conformal (preserves shape)	Lambert, Mercator
Thematic Maps	Equal-area	Cylindrical, Albers

What happens if I mix projections?

The simple answer is that the data will not overlay, as shown in the following figure.

<http://www.utexas.edu/depts/grg/gcraft/notes/mapproj/gif/threepro.gif>



I have heard of Universal Transverse Mercator (UTM). What is that about?

UTM is a specialized application of the Transverse Mercator projection. The globe is divided into 60 north and south zones with each having its own central meridian. The origin for each zone is its Central Meridian and the Equator. To eliminate negative coordinates, the coordinate system alters the coordinate values at the origin. The value given to the central meridian is the false easting, and the value assigned to the equator is the false northing. A false easting of 500,000 meters is applied. A north zone has a false northing of zero, while a south zone has a false northing of 10,000,000 meters.

Properties

- Shape - UTM is conformal – shapes are preserved in small areas.
- Area - minimal distortion of larger shapes occurs within the same zone.
- Distance – local angles are true
- Direction - Scale is constant along the central meridian, but at a scale factor of 0.9996 to reduce lateral distortion within each zone.

Limitations

- Designed for a scale error not exceeding 0.1 percent within each zone.
- Error and distortion increase for regions that span more than one UTM zone. UTM is not designed for areas that span more than a few zones.

2. Datum

A datum defines the position of the spheroid relative to the center of the earth. It provides a frame of reference for measuring locations on the surface of the earth by defining the origin and orientation of latitude and longitude lines. Whenever you change the datum, or more correctly, the geographic coordinate system, the coordinate values of your data will change. Local datum, such as the North American Datum of 1983 (NAD 83) are designed to be used in a specific area.

The North American Datum of 1927 uses the Clarke 1866 spheroid to represent the shape of the earth. The origin of this datum is Meades Ranch in Kansas. Many NAD 1927 control points were calculated from observations taken in the 1800s. These calculations were done manually and in sections over many years. The result of this approach was errors between stations.

The North American Datum of 1983 is based upon both earth and satellite observations, using the GRS80 spheroid. The center of this datum is the center of the earth. Locations between NAD 27 and NAD83 shift by as much as 500 feet, however NAD 83 is compatible with GPS data. The Geodetic Glossary defines geodetic datum as:

1. *"A set of constants specifying the coordinate system used for geodetic control, i.e., for calculating the coordinates of points on the Earth."*
2. *"The datum, as defined in (1), together with the coordinate system and the set of all points and lines whose coordinates, lengths, and directions have been determined by measurement or calculation."*

(From National Geodetic Survey, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, MD, September 1986, pp. 54

<http://www.ngs.noaa.gov/faq.shtml#WhatDatum>)

These differing definitions require caution when using the word "datum." The first definition makes datum synonymous with the selection of a reference coordinate system (origin and orientation). The second definition makes datum synonymous with a list of coordinates of the control points. When the first definition is used, the published coordinates of control points can change when better measurements allow better determinations. With the second definition, a change in coordinates should result in a new datum. The National Geodetic Survey (NGS) has used the first definition for NAD 1983.

What are NAD 27 and NAD 83?

The North American Datum of 1927 (NAD 27) is "The horizontal control datum for the United States that (was) defined by (a) location and azimuth on the Clarke spheroid of 1866, with origin at (the survey station) Meades Ranch." ... The geoidal height at Meades Ranch (was) assumed to be zero. " Geodetic positions on the North American Datum of 1927 were derived from the (coordinates of and an azimuth at Meades Ranch) through a readjustment of the triangulation of the entire network in which Laplace azimuths were introduced, and the Bowie method was used." (Geodetic Glossary, pp. 57)

The North American Datum of 1983 (NAD 83) is "The horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System 1980.

"This datum, designated as NAD 83, is the new geodetic reference system. ... NAD 83 is based on the adjustment of 250,000 points including 600 satellite Doppler stations which constrain the system to a geocentric origin." (Geodetic Glossary, pp 57)

Why did National Geodetic Survey (NGS) change from NAD 27 to NAD 83?

NAD 83 was computed by the geodetic agencies of Canada (Federal and Provincial) and the National Geodetic Survey for several reasons. The horizontal control networks had expanded piecemeal since 1933 to cover much more of the countries and it was very difficult to add new surveys to the network without altering large areas of the previous network. Field observations had added thousands of accurate Electronic Distance Measuring Instrument (EDMI) base lines, hundreds of additional points with astronomic coordinates and azimuths, and hundreds of Doppler satellite determined positions. It was also recognized that the Clarke Ellipsoid of 1866 no longer served the needs of a modern geodetic network. For an in-depth explanation see NOAA Professional Paper NOS 2 "The North American Datum of 1983", Charles R. Schwarz, Editor, National Geodetic Survey, Rockville, MD 20852, December 1989.

How do the horizontal datum differ? Which should I use?

The NAD 27 was based on the Clarke Ellipsoid of 1866 and the NAD 83 is based on the Geodetic Reference System of 1980. The NAD 27 was computed with a single survey point, MEADES RANCH in Kansas, as the datum point, while the NAD 83 was computed as a geocentric reference system with no datum point. NAD 83 has been officially adopted as the legal horizontal datum for the United States by the Federal government, and has been recognized as such in legislation in 44 of the 50 states. The computation of the NAD 83 removed significant local distortions from the network which had accumulated over the years, using the original observations, and made the NAD 83 much more compatible with modern survey techniques.

What is HARN or HPGN?

A High Accuracy Reference Network (HARN) and a High Precision Geodetic Network (HPGN) were two designations used for a statewide geodetic network upgrade. The generic acronym HARN is now used for both HARN and HPGN and was adopted to remove the confusion arising from the use of two acronyms. A HARN is a statewide or regional upgrade in accuracy of NAD 83 coordinates using Global Positioning System (GPS) observations. HARNs were observed to support the use of GPS by Federal, state, and local surveyors, geodesists, and many other applications. The cooperative network upgrading program began in Tennessee in 1986. The last field observations were completed in Indiana in September 1997 after horizontally upgrading some 16,000 survey stations to A-order or B-order status. Horizontal A-order stations have a relative accuracy of 5 mm +/- 1:10,000,000 relative to other A-order stations. Horizontal B-

order stations have a relative accuracy of 8 mm +/- 1:1,000,000 relative to other A-order and B-order stations. Of these 16,000 stations, NGS has committed to maintaining about 1,400 survey stations, named the Federal Base Network, and the various states will maintain the remainder.

What are NGVD 29 and NAVD 88?

"The National Geodetic Vertical Datum of 1929: The name, after May 10, 1973, of (the) Sea Level Datum of 1929." (Geodetic Glossary, pp. 57)

"Sea Level Datum of 1929: A vertical control datum established for vertical control in the United States by the general adjustment of 1929." "Mean sea level was held fixed at the sites of 26 tide gauges, 21 in the U.S.A. and 5 in Canada. The datum is defined by the observed heights of mean sea level at the 26 tide gauges and by the set of elevations of all bench marks resulting from the adjustment. A total of 106,724 km of leveling was involved, constituting 246 closed circuits and 25 circuits at sea level." "The datum (was) not mean sea level, the geoid, or any other equipotential surface. Therefore it was renamed, in 1973, the National Geodetic Vertical Datum on 1929." (Geodetic Glossary, pp. 56)

The North American Vertical Datum of 1988 (NAVD 88) is the vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations. It held fixed the height of the primary tidal bench mark, referenced to the new International Great Lakes Datum of 1985 local mean sea level height value, at Father Point/Rimouski, Quebec, Canada. Additional tidal bench mark elevations were not used due to the demonstrated variations in sea surface topography, i.e., the fact that mean sea level is not the same equipotential surface at all tidal bench marks. ("Results of the General Adjustment of the North American Datum of 1988," Surveying and Land Information Systems Vol. 52, No. 3, 1992 pp. 133-149).

Why did NGS change from NGVD 29 to NAVD 88?

NAVD 88 was computed for many of the same reasons as NAD 83. About 625,000 km of leveling had been added to the NGVD since 1929. Thousands of bench marks had been subsequently destroyed and many others had been affected by crustal motion, postglacial rebound, and subsidence due to the withdrawal of underground fluids. Distortions amounting to as much as 9 meters had been seen due to forcing the new leveling to fit the NGVD 29 height values. ("Results of the General Adjustment of the North American Datum of 1988," Surveying and Land Information Systems Vol. 52, No. 3, 1992 pp. 133-149)

What is WGS 84? Does it change?

WGS 84 is the World Geodetic System of 1984. It is the reference frame used by the U.S. Department of Defense (DoD) and is defined by the National Imagery and Mapping Agency (NIMA) (formerly the Defense Mapping Agency). WGS 84 is used by DoD for all its mapping, charting, surveying, and navigation needs, including its GPS "broadcast" and "precise" orbits. WGS 84 was defined in January 1987 using Doppler satellite

surveying techniques. It was used as the reference frame for broadcast GPS Ephemerides (orbits) beginning January 23, 1987. At 0000 GMT January 2, 1994, WGS 84 was upgraded in accuracy using GPS measurements. The formal name then became WGS 84 (G730) since the upgrade date coincided with the start of GPS Week 730. It became the reference frame for broadcast orbits on June 28, 1994. At 0000 GMT September 30, 1996 (the start of GPS Week 873), WGS 84 was redefined again and was more closely aligned with International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF) 94. It is now formally called WGS 84 (G873). WGS 84 (G873) was adopted as the reference frame for broadcast orbits on January 29, 1997.

I have heard rumors of a new reference system/datum. What are NGS's plans?

Between 1987 and 1997, the National Geodetic Survey, in cooperation with other Federal, State and local surveying agencies has conducted a resurvey of the United States using Global Positioning System (GPS) observations often referred to as the High Accuracy Reference Networks (HARNs). All 50 states, American Samoa, Guam, Puerto Rico and the Virgin Islands have now been connected with a network of A-order and B-order horizontal control points. Continued improvements in GPS technology and requirements from users of spatial data will eventually require a transition to an improved global reference frame based on the International Terrestrial Reference Frame (ITRF). Positions relative to ITRF differ from the existing North American Datum of 1983 (NAD 83) by approximately 1 meter in horizontal position and 1 meter in ellipsoidal height. NGS already publishes ITRF coordinates for all Continuously Operating Reference Stations (CORS), and will over the next 3-5 years implement an adjustment to include the HARNs and other GPS data that have been submitted to NGS for adjustment and publication. NGS will continue to maintain and improve NAD 83 as the official datum of the United States, until such time as it will no longer support requirements for surveying, mapping and navigation. NGS is currently conducting workshops and seminars around the country to educate data users concerning these and other improvements to the National Spatial Reference System.

3. Coordinate Systems

A geographic coordinate system is a non-projected coordinate system that includes a datum, a prime meridian and an angular unit of measure.

Is the State Plane Coordinate System a projection? How does the State Plane Coordinate System relate to projections?

The State Plane Coordinate System is not a projection. It is a coordinate system that divides the United States into over 120 numbered zones. Three conformal projections were chosen:

- Lambert Conformal Conic for states that are longer east–west, such as Tennessee and Kentucky
- Transverse Mercator projection for states that are longer north–south, such as Illinois and Vermont

- Oblique Mercator projection for the panhandle of Alaska, because it lays at an angle.

To maintain an accuracy of one part in 10,000, it was necessary to divide many states into zones. Each zone has its own central meridian or standard parallels to maintain the desired level of accuracy. Zone boundaries follow county boundaries. Indiana is divided into two zones – Indiana East and Indiana West.

4. Units of Measure

When should I use meters and when should I use feet?

The primary units used to measure distance are the meter and the U.S. Survey foot. UTM distances are usually expressed in meters. State Plane distances are usually expressed in U.S. Survey Feet, and tenths and hundredths of feet, when using NAD27 datum; and, meters when using NAD83.

What is the difference between a foot and a surveyor's foot?

The definition of the yard resulted in the imperial foot being 0.3048 meters exactly. However, in the USA, in 1866 the meter was declared to be 39.37 inches. This made the US foot to be 0.3048006096---- meter (approx.). Not a lot of difference? It was to scientists and engineers, especially as measuring instruments became more and more accurate. It was not until the 1950's that agreement was reached on that, when the imperial definition was adopted by the USA.

In the meantime, most of the USA had been surveyed using the 1866 definition that became identified as the US Survey Foot. Metrication of the survey undertaken towards the end of the 1900's used, for conversion purposes, the fact that 39.37 US(survey)feet = 12 meters (exactly).